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ANALYSIS OF EGG-LAY DATES OF BALD EAGLES AS A POTENTIAL INDICATOR OF GLOBAL CLIMATE CHANGE

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ANALYSIS OF EGG-LAY DATES OF BALD EAGLES AS A POTENTIAL INDICATOR OF GLOBAL CLIMATE CHANGE

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ABSTRACT

The effects of climate change on many wildlife species is a new area of research. Long-term data sets on raptor populations may hold the key to documenting these impacts from local to ecosystem scales. The Michigan bald eagle (*Haliaeetus leucocephalus*) population has been monitored continuously since 1961, and virtually all reproductive outcomes are known since 1963. The bald eagle population at Voyageurs National Park, Minnesota has been monitored continuously since 1973. Though these data sets are extensive, little is known about the effects of climate change on egg laying dates in sea eagles (*Haliaeetus* spp). Understanding these effects could ultimately provide valuable information regarding the overall impact of climate change on entire ecosystems. This preliminary study was conducted to determine the effects of environmental temperature change on the average lay date of bald eagle eggs in MI and MN. In addition, the relationships of change in egg lay date with elevation, water type, latitude/longitude, breeding area, and distance from the Great Lakes were evaluated in the MI study area; the relationships of change in egg lay date with ice-off and lake location were evaluated in the MN study area. In both study areas, the earliest lay dates of nesting pairs were derived utilizing morphometric measurements of nestlings. The MI study period was from 1988-2008, and included 442 nest sites and over 2,300 first egg lay dates. We found both significant and inverse trends in Julian Date for the first lay date that averaged -0.39 d/y over this time period ($P<0.0001$). Lay dates were further examined at three geographical scales to determine if any trends were evident: Anadromous (AN), Great Lakes (GL), and Inland (IN) breeding areas. AN lay dates

averaged -0.95 d/y ($P<0.0001$), GL lay dates averaged -0.75 d/y ($P<0.0001$), and IN lay dates averaged -0.32 d/y ($P<0.0001$) over the study period. The MN study period was from 1989-2009, and included 115 nest sites. We found a decreasing but not statistically significant trend in Julian Date for the first lay date that averaged -0.047 d/y over this time period. After narrowing the MN data set to only nests with 5 or more years of visitation, the trend was still not significant, averaging -0.180 d/y. From the MI data, it is apparent that there may be a correlation between milder winters and earlier lay dates of breeding pairs. Our MN results may suggest that eagles are not responding to climate change, but the reason behind this may be that all MN lakes are inland and the power of the dataset was low. The relatively small area would have needed over 2000 records to show a significant trend. Eagles and raptors may now be warning us of the impacts of climate change, much like they did earlier with impacts of DDT and other environmental pollutants.

DEDICATION

I dedicate this thesis to my family: my parents, Wayne and Frances Garrison, sister, Chrissy, and brother, Chris. I also dedicate this work to my true love, Matt Bloodgood, and my closest and dearest friends from Clemson and back home: Ian and Steph Sullivan, Blair Kruger, Jeannie Burnett, Simon Mandell, Angela Woodard, Lindsey Doxtater and all the ladies in the Lehotsky Hall basement. Thank you. I could not have accomplished this without all of your support and faith in me.

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CHAPTER ONE

INTRODUCTION

Eagle Monitoring

The bald eagle (*Haliaeetus leucocephalus*) is considered a primarily year-round resident breeding species along the shorelines and islands of the Great Lakes (Shear et al. 2003). Surveys for bald eagle reproductive activity have been conducted yearly in Michigan since the early 1960s. Surveys of reproductive activity have been conducted at Voyageurs National Park, Minnesota, since 1973. Because of their global distribution, well-studied life histories, measureable and predictable endpoints that are directly linked to the effects of stressors, and their importance to humans, birds are one of the most important wildlife indicator species currently used (Gilbertson 1990; IJC 1991; IJC1992; Bowerman et al. 2002; Helander et al. 2008).

The Bald Eagle as an Indicator Species

The bald eagle is one of the most studied birds in North America. The International Joint Commission proposed this species as a biological indicator species of toxic effects of organochlorine compounds on piscivorous wildlife and the effects of bioaccumulation and biomagnification in the Great Lakes (IJC 1991). The strength of using the bald eagle as an indicator species for climate change lies in its extensive breeding records, which allow a near total count of all breeding pairs and their reproductive outcome. We therefore have a population "measure" rather than relying on an estimate or "index" of the actual population (Bowerman et al. 1998). Another strength of using bald eagles as indicator species is the amount of information that is known about

their life history, including the impact of various stressors such as environmental toxicants and human activities on the eagles' ability to reproduce (Bowerman et al. 2002). The bald eagle's status as the national symbol of the United States also makes it a great tool for public education about environmental impacts.

As aquatic tertiary predators, sea eagles (*Haliaeetus* spp.) are particularly threatened by bioaccumulation and biomagnification polychlorinated biphenyl ethers (PCBs) and organochlorine pesticides including dichloro-diphenyl-trichloroethane (DDT) and its metabolites (Bowerman et al. 1995; Anthony et al. 1999; Herzke et al. 2002; Kubistova et al. 2003). The widespread use of these chemicals in the 1950s and their subsequent release into the environment led to a significant decline in eagle populations worldwide. These declines led to many long-term population monitoring programs beginning in the 1960s, many of which are still in use today (Gerrard et al. 1992; Potapov et al. 2000; Bowerman et al. 2002; Haworth et al. 2006; Helander et al. 2008; Nye 2008). In Michigan, the bald eagle population has been continuously monitored on a statewide basis since 1961 (Bowerman et al. 1998). At Voyageurs National Park (VNP), Minnesota, the population has been continuously monitored since 1973 (Grim & Kallemeyn 1995). The North American bald eagle population has increased since the ban of DDT and other persistent compounds in the 1970s (Bowerman et al. 1998). Recently, however, a new threat has become apparent—climate change.

Climate Change

The effect of climate change on wildlife species is a new area of research. Nesting chronology has recently been shown to be an effective measure of environmental

alterations due to global climate change (Grand 1992; Crick & Sparks 1999). The negative effects of organic pollutants on birds in the 1950s and 1960s increased the monitoring of avian populations in many regions of the world; while not their original purpose, these data can now be analyzed for climate change effects. Many avian populations are nesting earlier and these changes have been directly correlated to changes in weather patterns and/or changes in ecological constraints on nesting and carrying capacity (Brown et al. 1999; Dunn and Winkler 1999; Rubolini et al. 2007; Møller 2008). More recently, rates of phenological shifts due to climate change have been shown to vary among species, functional groups, and trophic levels, causing a risk of temporal mismatch in trophic level interactions (Thackeray et al. 2010).

During the past century, global surface temperatures have increased at a rate of 0.05°C per decade, but this rate has increased to 0.16°C per decade in the last 30 years. Eight of the warmest years on record have occurred since 2001 (NOAA 2008). This trend of warming is seen in both daily maximum and minimum temperatures, with minimum temperatures increasing at a faster rate than maximum temperatures. This in turn has caused a large reduction in the number of days below freezing (IPCC 2007). These temperature fluxes are not uniform: average temperature changes at the poles are more extreme than those at the equator, with the warmest above-average temperatures occurring throughout the high latitude regions of the Northern Hemisphere including much of Europe and Asia (NOAA 2008). Average temperatures in the Arctic have increased at almost twice the global rate in the past 100 years (IPCC 2007).

The effects of climate change are not limited to changes in temperatures. Precipitation, sea level, and snow and ice cover are also affected. Precipitation has generally increased since 1900 over land north of 30 degrees N, but has mostly declined in the tropics. Sea level has risen worldwide approximately 12-22 cm in the last century, primarily due to melting of glaciers and expansion of ocean water caused by warmer ocean temperatures. In the United States, sea level has been rising 2-3mm per year, though this varies in different regions, with the greatest rises occurring around the Gulf of Mexico and decreases occurring around Alaska (IPCC 2007). Changes in snow and ice cover have varied greatly over time. A 30 year downward trend of 11.7 percent per decade, however, has been documented in the September Northern Hemisphere average sea-ice extent (NOAA 2008).

Objectives

As the global climate continues to change, the need for research on how it alters the distribution, abundance, and population dynamics of species will increase. Many existing studies use birds because of their importance as indicator species; however, little research exists on the effects of climate change on egg laying dates.

The goals of this research project were to:

1) Determine Julian lay dates of bald eagle eggs in MI and MN utilizing Bortolotti's method of ageing nestlings;
2) Determine if lay date changed over the study period by using a regression model with lay date as the response variable and year as the predictor variable;

3) Determine if change in lay date correlated with other habitat variables besides year, including: temperature, elevation, ice-out, latitude and longitude, distance from major water sources, and habitat location;
4) Determine if trends in lay date were more evident in areas with more years of observations during the study period.

This thesis was written in journal style and organized into four chapters, two of which are intended for publication and consist of an introduction, methods, results, and discussion. Repetition in some sections (i.e. Introduction, Methods, Results, Discussion, and Literature Cited) may occur. The two publishable chapters are preceded by this Introduction chapter and followed by an overall Conclusions chapter.

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CHAPTER TWO

MICHIGAN

Introduction

Birds have been used by humans as indicators of adverse environmental factors for centuries. The use of canaries in coal mines is just one prime example. Endpoints including effects on bird reproduction, chronic and acute lethality, teratagenic effects, nesting density, and simple presence/absence are just a few of the measures that humans use to determine the health of our environment (Bowerman et al. 1995; Bowerman 2003). Because of their global distribution, well studied life histories, measurable and predictable endpoints that are directly linked to effects of stressors, and their importance to humans, birds are one of the most important wildlife indicator species currently used (Gilbertson 1990; IJC 1991; IJC 1992; Bowerman et al. 2002; Helander et al. 2008).

Birds of prey were among the first avian species to show widespread detrimental impacts from increased use of agricultural pesticides in the post-WWII era (Carson 1962; ATSDR 2002). Sea eagles (*Haliaeetus* spp.), because of their status as aquatic tertiary predators, were particularly impacted by bioaccumulation and biomagnification of polychlorinated biphenyl ethers (PCBs) and organochlorine pesticides including dichloro-diphenyl-trichloroethane (DDT) and its metabolites (Bowerman et al. 1995; Anthony et al. 1999; Herzke et al. 2002; Kubistova et al. 2003). The declining populations of these species across the globe in the 1950s resulted in long term population monitoring programs. Many of these programs began in the early 1960s, and many are still in use today (Gerrard et al. 1992; Potapov et al. 2000; Bowerman et al. 2002; Haworth et al.

2006; Helander et al. 2008; Nye 2008). In Michigan, the bald eagle (*H. leucocephalus*) population has been continuously monitored on a statewide basis since 1961 (Bowerman et al. 1998).

Nesting chronology has recently been shown to be an effective measure of environmental alterations due to global climate change (Grand 1992; Crick & Sparks 1999). Because long term data sets are available for many species and at many locations around the world, avian population data can be used to test hypotheses pertaining to abiotic stressors and climate change model sensitivity. Many avian populations are nesting earlier and these changes have been correlated to changes in weather patterns and/or changes in ecological constraints on nesting and carrying capacity (Brown et al. 1999; Dunn & Winkler 1999; Rubolini et al. 2007; Møller 2008).

Here we report the results of a study on nesting chronology of bald eagles in Michigan, 1988-2009. The primary objective of this study was to evaluate bald eagle nesting chronology in Michigan for indicators of effects from global climate change. Secondary objectives were to: 1) determine the presence of significant relationships between Great Lakes (GL), Anadromous (AN) and Inland (IN) categories of bald eagle breeding areas from 1988 to 2006, 2) further analyze relationships between the IN category by evaluating variables of breeding area location parameters, habitat type, elevation, latitude/longitude, and temperature, and 3) determine whether or not relationships exist within breeding areas with more than 10 years of monitoring data between 1988 and 2008 in relation to monthly temperatures.

Methods

Study Area

Michigan is divided into two ecological subregions of the United States: South Central Great Lakes and Northern Great Lakes. Elevation in the South Central Great Lakes subregions ranges from 177-390 m. Precipitation averages 750 to 930 mm. Temperature averages 7 to 10 ºC. The elevation in the northern Great Lakes ranges from 177-526 m. Average annual precipitation ranges from 680 to 1090 mm. Lake-effect snowfall is considerable in some parts, ranging from 1800 to 6330 mm. Annual temperature averages range from 4 to 6 ºC (McNab & Avers 1994). The Great Lakes ecosystem is the largest body of freshwater in the world containing 18% of the world's supply. The basin covers 246,049 square km with 14,484 km of shoreline, 5,000 tributaries, and the watershed has a drainage area of 745,917 square km (GLBET 2004). The system extends from roughly 41 to 51 degrees North latitude and 75 to 93 degrees West longitude (Botts & Krushelnicki 1987). Significant ecological systems include terrestrial and wetland inlands, lake plains, tributaries, coastal marshes and shorelines, and open lake (Rankin & Crispin 2006). The Great Lakes ecosystem supports a significant amount of biological diversity that can support complex food webs.

Data Collection

Our monitoring project's aerial surveys were conducted by Michigan Department of Natural Resource (MDNR) pilots and contracted observers to establish which nests within the state's breeding areas were active. An observer on each flight noted the nest tree species, reproductive status (e.g., adult incubating/brooding behavior, eggs, or

chicks), and determined location (latitude and longitude) with Global Positioning System units (GPS). The first annual survey was conducted in March or early April to establish nest occupancy. The second aerial survey occurred in early May through mid June to determine nesting success or failure. If the nest was successful, the number of young, stage of development, tree condition, and nest access from the ground were recorded. From the observer's notes, our field crews were directed to the nests. We sampled nestling eagles at five to nine-weeks of age, from early May to July each year. We used ground-based GPS to determine exact nest locations.

At the nest, a trained and equipped crew member was dispatched up the nest tree. Once the climber was secure at the nest, a nestling eagle was captured, placed in a restraining bag, and lowered to the ground. Nestlings were then removed from the restraining bag then placed on their backs with their feet bound with elastic bandages to avoid injury to the bird or handler. Eighth primary feather and footpad lengths were measured with a ruler. With these measurements, we followed procedures developed by Bortolotti (1984) to determine sex and then estimate the age of the nestling. After sampling was completed, we banded the nestlings with a size 9 U.S. Fish and Wildlife Service (USFWS) rivet band, put them back in the restraining bag and then returned them to the nest. Capture and sampling methods were conducted according to approved Clemson University Animal Use Protocols (AUP). Handling methods were also approved AUP methods and conducted under USFWS banding permits.

Data Analyses

The analysis of changes in lay day of year (DOY) from 1998 through 2008 proceeded in five stages.

Overall

The first stage involved a simple regression model of all data with lay DOY as the response variable and year as the predictor variable. We used PROC REG of SAS to analyze this model (SAS 2007). We realized that this trend could include factors affecting lay DOY besides year, such as large scale variables like general location and small scale environmental variables like temperature and elevation. To try to ensure that the relationship we saw was primarily due to year and not the other possible variables, we proceeded to further steps in the analysis.

Category

The second stage of analysis divided breeding areas into three general location categories: Great Lakes (GL), Anadromous (AN), and Inland (IN) (Table 2.1). GL breeding areas were defined as being within 8.0 km of Great Lakes shorelines, while AN sites were along tributaries open to Great Lakes fish runs. IN breeding areas were defined as being greater than 8.0 km from the Great Lakes shorelines and not along tributaries open to Great Lakes fish runs (Bowerman et al. 1994; Roe 2001; Bowerman et al. 2003). Each of these three categories was evaluated using a simple linear regression with lay DOY as the response variable and year as the predictor variable. These regressions were first performed with all lay DOYs included for each year and again with lay DOY averaged for each year.

Inland Breeding Areas

The third stage of analysis involved evaluation of IN breeding areas only. This involved including breeding area as a random effect in the model to adjust for inherent differences in lay DOY across the breeding areas, and to ensure these differences were not confounded with the year predictor variable. We analyzed this model with mixed model procedures for longitudinal data with PROC GLIMMIX of SAS.

Next, a fourth stage was conducted to determine if any characteristics of the IN breeding area, besides year, was involved in the relationship between lay DOY and year. We used a multiple regression analysis to evaluate location of breeding area (LOC), habitat type, elevation, latitude/longitude, and distance to the Great Lakes. LOC was further subdivided by peninsula: Lower Peninsula (LP) and Upper Peninsula (UP); and which lake was in closest proximity: Lake Michigan (M), Lake Superior (S), Lake Huron (H), or Lake Erie (E). Habitat type classifications were designated Lake (LAK), River (RIV), or Dam (DAM). We entered latitude and longitude data in ArcGIS to measure the distance of each nest from the Great Lakes in 5 km buffer zones (ESRI 2008). We included all characteristics as covariates in a multiple regression, and a mixed model procedure was performed with PROC GLIMMIX of SAS.

Inland "Best 35" Breeding Areas

The fifth and final stage involved creating a data set within the IN category that included only breeding areas with visitation records of ten years or longer. This ensured that the trends were consistent when only the "best" part of the data set was included and breeding areas with limited records did not have an undue influence on the analysis; this

yielded 35 breeding areas that were termed the "best 35" (Table 2.1). Breeding area was again included as a random effect in the model to adjust for inherent differences in lay DOY across the breeding areas, and to ensure these differences were not confounded with the year predictor variable. A linear regression was used to evaluate lay DOY over time for just the Inland "best 35." The relationship between mean temperatures for January, February, March, and April and lay DOY were then evaluated using a simple linear regression. To determine average monthly temperature for January through April, we used data from NASA weather stations closest to each breeding area (NASA GISS 2010; Table 2.2).

Results

Overall

The overall relation between Julian Date for the first lay date and year from 1988-2006 was negative and significant (slope= -0.39 d/y, t = -6.59, df = 2104, P<0.0001, r^2=0.0202).

Category

Julian dates of first egg laid were earlier for breeding areas from GL, AN, and IN categories between 1988 and 2006 (Figures 2.2, 2.3, and 2.4). Eagles in breeding areas within the GL category laid first eggs significantly earlier (slope= -0.75 d/y, t= -6.90, df=544, P<0.0001, r^2=0.0806). Eagles in breeding areas within the AN category laid first eggs significantly earlier (slope= -0.95 d/y, t= -4.92, df=149, P<0.0001, r^2=0.1404). Eagles in breeding areas within the IN category also laid first eggs significantly earlier (slope= -0.32 d/y, t= -4.57, df=1409, P<0.0001, r^2=0.0146). After averaging lay DOY

for each year, the GL category was still negative and significant (slope= -0.69 d/y, *t*= -5.06, df=18, P<0.0001, r^2=0.5773). After averaging lay DOY for each year, the AN category was also still negative and significant (slope= -0.87 d/y, *t*= -2.98, df=18, P<0.00415, r^2=0.3052). After averaging lay DOY for each year, the IN category was still negative, however this relationship was barely significant (slope= -0.27 d/y, *t*= -1.81, df=18, P=0.0439, r^2=0.1125). Due to the great variability of additional factors that could influence lay dates among IN breeding areas, and to avoid making a type I error, we conducted additional analyses with this category.

Inland Breeding Areas

IN breeding area characteristics showed no significance individually or in combination, which indicated that the effect of breeding area could not be easily explained as a simple function of the characteristics. We therefore omitted LOC, habitat type, elevation, and latitude/longitude from further analysis. When breeding area was included as a random effect to adjust for inherent differences, a significant relationship was observed (slope= -0.33, t = -6.23, df = 1141, P<0.0001, r^2=0.6710).

Inland "Best 35" Breeding Areas

When corrected for breeding area, lay DOY for the IN "best 35" was becoming significantly earlier over time (slope= -0.26, t = -2.99, df = 375, P=0.0015, r^2=0.6691). Of the 35 breeding areas, 23 had negative values six of which were significant at $\alpha \leq 0.05$ (Table 2.3). We found a significant, inverse relationship between January mean temperature and lay date (slope= -0.515 d/°C, t = -3.87, df = 363, P<0.0001, r^2=0.6541). Mean temperature data for February also showed a significant inverse relationship to lay

date (slope= -0.601 d/°C, t = -4.99, df = 363, P<0.0001, r^2=0.6834), as did mean temperature for March (slope= -0.360 d/°C, t = -1.80, df = 358, P=0.03615, r^2=0.6369). Mean temperature data for April also showed a significant inverse relationship with lay date (slope= -0.935 d/°C, t = -4.07, df = 353, P <0.0001, r^2=0.6763) (Table 2.4).

Discussion

Habitat Relationships

One reason that lay dates could vary across a landscape is because of the habitats that nests are surrounded by. Lay date may change depending on whether the nest is built near a lake, river, or dam. Within Inland breeding areas, lakes would be expected to remain iced-over longest because currents and turnover in rivers and dams break up ice sooner than ice breaks up in lakes. This would suggest that eagles near rivers and dams may breed sooner because food is available sooner in these areas. In our model, however, habitat was not significant in determining lay date. Lay dates may also be expected to vary based on how close they are to major water sources. In our model, however, distance from the Great Lakes was not a significant predictor of lay date.

Temperature Data

Another reason that lay dates could vary across a landscape is because of variations in temperature. In the evaluation of the 35 IN breeding areas, temperature in the months of January through April all had a significant relationship to lay date. This could have considerable implications for chick health and growth. If lay date is offset from food availability, for instance, chicks could starve to death (Murton and Westwood

1977). This relationship between temperature and lay date may be an indicator of the effect that climate change could have on eagles.

Location on Earth

There are several factors that may contribute to temperature change across a landscape. One reason is location. Michigan is divided into two ecological subregions of the United States: South Central Great Lakes and Northern Great Lakes. The system extends from roughly 41 to 51 degrees North latitude and 75 to 93 degrees West longitude (Botts & Krushelnicki 1987). In our model, latitude and longitude were not significant predictors of lay date.

Elevation

Another reason why temperature may vary over a landscape is elevational changes. Elevation in the South Central Great Lakes subregions ranges from 580 to 1,280 ft (175-396 m), while elevation in the northern Great Lakes ranges from 580 to 1,725 ft (176-259 m). In our model, elevation of nest sites was also not a significant predictor of lay date. Because habitat, location on earth, and elevation did not contribute significantly to the change in lay date over time, another driving force must be causing lay dates to gradually become earlier each year.

Comparison to Other Species Lay Dates

Related studies show that climate change increases competitive relationships (Ahola et al. 2007), causes population declines (Both et al. 2006), causes range shifts and extinction (Sekercioglu 2008), and alters breeding behavior (Carey 2009; Crick, 2004; Seavy et al. 2008). Earlier nesting chronologies have been demonstrated in a variety of

species. In a population of Mexican jays (*Aphelocoma ultramarina*) in Arizona, warmer minimum temperatures before and during breeding from 1971 to 1998 caused dates of first nest and first clutch to become earlier by 10.8 and 10.1 days, respectively (Brown et al. 1999). One data set spanning 57 years found that laying data was related to temperature or rainfall for 31 of 36 species (Crick and Sparks 1999). A 21 year study of marsh tits (*Parus palustris*) revealed a significant relationship between mean laying date and air temperature (Dolenec 2006). In another study from 1980 to 2002, collared flycatchers (*Ficedula albicollis*) bred an average of 0.4 days/year earlier (Weidinger and Kral 2007). This was correlated with an increase in temperature. Increase in May temperatures combined with reduced human interference at nest sites was correlated with hen harrier (*Circus cyaneu*) population increases over a 20 year period in Wales (Whitfield et al. 2008). Date of egg-laying in tree swallows (*Tachycineta bicolor*) in North America from 1959-1991 advanced up to 9 days (Dunn and Winkler 1999). In a study of black kites in Italy from 1994-2002, nesting was becoming earlier by 0.4 days/year (Sergio 2003). A study of red-winged blackbirds (*Agelaius phoeniceus*) in Ontario over 25 years correlated earlier nesting with the North Atlantic Oscillation Index (NAOI) and breeding season was shown to last longer, but there was no advancement in laying date (Weatherhead 2005). In one study of six bird species, laying date advanced in all cases except those where temperature was not variable over the 50 year period (Torti and Dunn 2005). In contrast to our study, an entire community of Antarctic seabirds studied over 55 years were shown to arrive 9.1 days later and lay eggs 2.1 days

later than 50 years previous (Barbraud et al. 2006). This is more likely linked, however, to a change in sea-ice extent and subsequent declines in food sources for these birds. In our study, AN (-0.95 d/y, $P<0.0001$), GL (-0.75 d/y, $P<0.0001$), and IN (-0.32 d/y, $P<0.0001$) breeding areas in MI show the greatest advance in lay date of any of the above studies.

Other Factors We Did Not Explore

Due to the nature of our long-term monitoring project, there were limitations to our reporting. The primary objective of our monitoring project was to evaluate trends of bio-accumulative chemicals of concern in the Great Lakes ecosystem, and all temperature data was gathered *post hoc* via the NOAA weather station database. On the basis of the location of bald eagle breeding areas, we were able to look at three spatial scales as well as five additional habitat characteristics that might have influenced lay dates. The simplest analysis of lay date over time revealed a significant, negative trend for GL and AN sites, so no additional analyses were conducted. Analyses of the IN breeding areas showed that there was a significant, inverse relationship between mean monthly temperature and annual lay dates. We did not evaluate minimum and maximum temperatures. Additional *post hoc* analyses could be conducted to determine the possible influence of minimum and maximum temperatures as well as precipitation (Brown et al. 1999); ice cover and the resulting effects on food availability (Møller 2008); and the NAOI (Rubolini et al. 2007). Previous studies have been conducted to survey effects of climate change on avian productivity (Sergio 2003). The Michigan bald eagle population has been steadily increasing since the banning of DDT and PCB in 1972 and 1976,

respectively; and currently there have been no observable effects that can be attributed to climate factors. Because of the robustness of our monitoring project, we will be able to conduct additional analyses as well as initiate new methods of collecting data in order to monitor the effects of climate change within the Great Lakes region.

Why We Saw What We Saw

Correlation data cannot prove that climate change is the reason behind the earlier laying we have reported, but other hypotheses are unconvincing. Our findings agree with those already indicated in other studies. Our study period of 20 years cannot be ignored, and warming temperatures over this period correlate with an advance in lay date over time.

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Table 2.1 List of the "best 35" Inland bald eagle breeding areas, which had at least 10 years of nest visitations.

Best 35 Breeding Areas				
AL_02 Alcona-Bamfield Pond	**GO_06** Poor/East Bay Lake	**IR_33** Buck/Armstrong Lake	**MY_01** Valentine Lake	**OT_01** Caulkins Creek
CB_02 Burt/Mullet Lake	**GO_22** Pomeroy Lake	**MM_05** Grand Rapids Dam North	**MY_05** Black River Ranch	**RO_01** Lake St Helen East
CR_03 Big Creek	**GO_23** Corey Lake (Sylvania)	**MM_07** Hermansville Pond	**MY_07** Avery Lake	**RO_06** Bear Creek Floodage
DI_10 Sturgeon Falls Dam-Millers	**GO_26** Mill Lake (Sylvania)	**MM_09** Miscauna	**OG_01** Rifle River Rec Area	**RO_07** North Bay Houghton Lake
GO_01 Langford Lake	**GO_30** Gogebic Lake South	**MN_06** Wellston	**OG_02** Stylus Lake East	**RO_11** West Twin/ Woods Lake
GO_03 Cisco Lake East	**GO_31** Michigan Bay-Big Lake	**MQ_18** Bony Falls Dam	**OS_02** Mio Pond West	**SC_12** Thunder Lakes
GO_05 Thousand Island/ Record Lake	**GO_36** West Bay Lake	**MT_11** Twin Islands	**OS_03** McKinley	**SC_15** Mud Lake Creek

Table 2.2 List of the "best 35" Inland bald eagle breeding areas, which had at least 10 years of nest visitations, with the weather station used to find temperature averages.

Best 35 Breeding Areas with Closest Weather Station

AL_02	**GO_06**	**IR_33**	**MY_01**	**OT_01**
Houghton Lake	Ironwood	Marquette	Cheboygan	Cheboygan
CB_02	**GO_22**	**MM_05**	**MY_05**	**RO_01**
Pellston	Ironwood	Green Bay	Cheboygan	Houghton Lake
CR_03	**GO_23**	**MM_07**	**MY_07**	**RO_06**
Houghton Lake	Ironwood	Green Bay	Cheboygan	Houghton Lake
DI_10	**GO_26**	**MM_09**	**OG_01**	**RO_07**
Iron Mountain	Ironwood	Green Bay	Houghton Lake	Houghton Lake
GO_01	**GO_30**	**MN_06**	**OG_02**	**RO_11**
Ironwood	Ironwood	Hart	Houghton Lake	Houghton Lake
GO_03	**GO_31**	**MQ_18**	**OS_02**	**SC_12**
Ironwood	Ironwood	Chatham Exp Farm #2	Houghton Lake	Munising
GO_05	**GO_36**	**MT_11**	**OS_03**	**SC_15**
Ironwood	Ironwood	Green Bay	Houghton Lake	Munising

Table 2.3 Thirty-five Inland bald eagle breeding areas which had at least 10 years of nest visitations and relationships between slope direction and significance of first egg laying dates from 1988-2008, in Michigan.

Slope Direction		**Number of Significant Negative Slopes**	
Positive	Negative	$\alpha \leq 0.05$	$\alpha \leq 0.15$
12	23	6	8

Table 2.4 Thirty-five Inland bald eagle breeding areas which had at least 10 years of nest visitations and relationships first egg laying dates and mean monthly temperature from 1988-2008, in Michigan.

Month	**Slope (Days)**	**P-value**
January	-0.51 (9.2)	0.0001
February	-0.60 (10.8)	<0.0001
March	-0.30 (5.4)	0.0001
April	-0.93 (16.7)	<0.0001

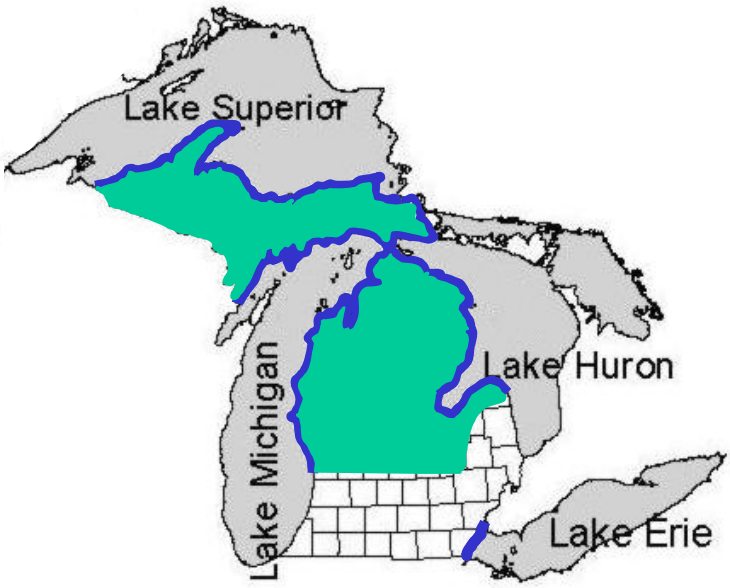

Figure 2.1 Locations of bald eagle breeding areas in Michigan (shaded areas) indicating interior breeding areas (green) and Great Lakes/Anadromous breeding areas (blue).

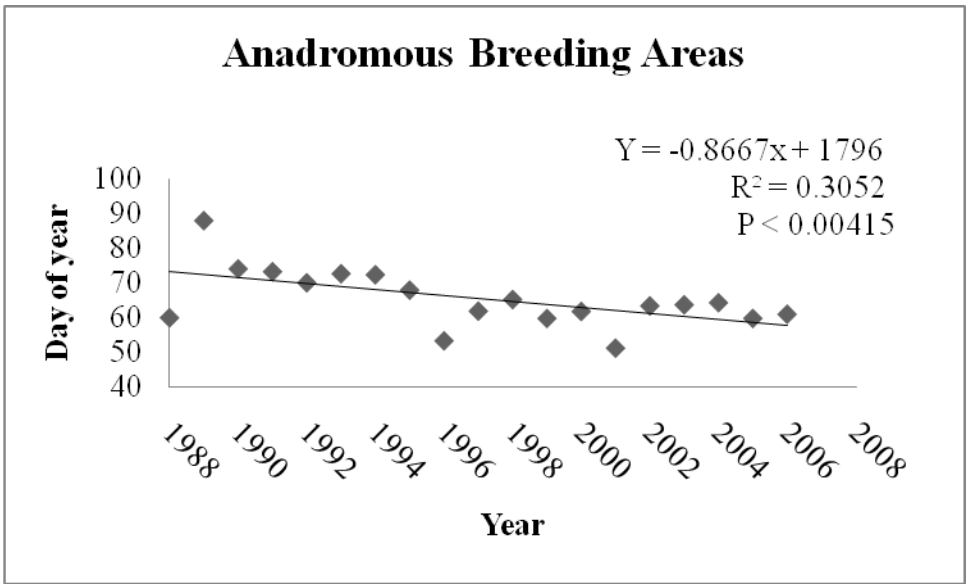

Figure 2.2 Mean Julian dates of first egg laid by nesting bald eagles in Anadromous breeding areas from 1988-2006.

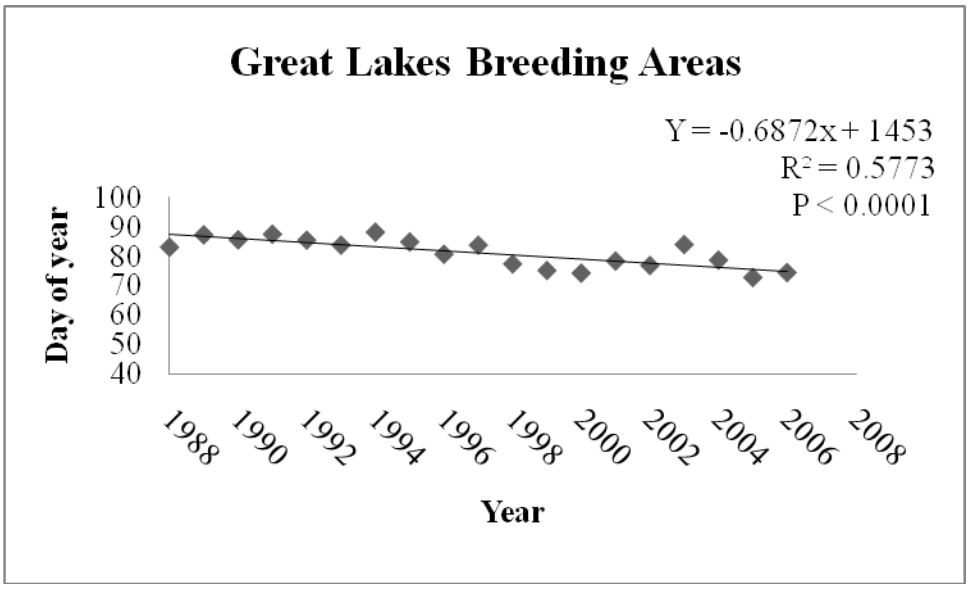

Figure 2.3 Mean Julian dates of first egg laid by nesting bald eagles in Great Lakes breeding areas from 1988-2006.

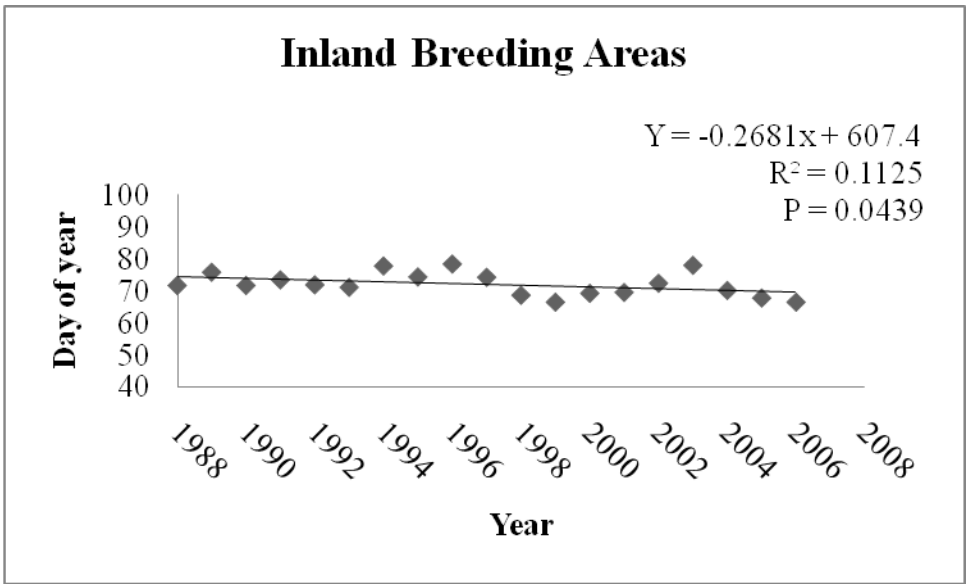

Figure 2.4 Mean Julian dates of first egg laid by nesting bald eagles in Inland breeding areas from 1988-2006.

CHAPTER THREE

VOYAGEURS NATIONAL PARK

Introduction

Because of their global distribution, well-studied life histories, measurable and predictable endpoints that are directly linked to the effects of stressors, and their importance to humans, birds are one of the most important wildlife indicator species currently used (Gilbertson 1990; IJC 1991; IJC 1992; Bowerman et al. 2002; Helander et al. 2008). The bald eagle (*Haliaeetus leucocephalus*) is one of the most studied birds in North America. The strength of using the bald eagle as an indicator species for climate change lies in its extensive breeding records, which allow a near total count of all breeding pairs and their reproductive outcome. We therefore have a population "measure" rather than relying on an estimate or "index" of the actual population (Bowerman et al. 1998).

As aquatic tertiary predators, sea eagles (*Haliaeetus* spp.) are particularly threatened by bioaccumulation and biomagnification of chemicals such as polychlorinated biphenyl ethers (PCBs) and organochlorine pesticides including dichloro-diphenyl-trichloroethane (DDT) and its metabolites (Bowerman et al. 1995; Anthony et al. 1999; Herzke et al. 2002; Kubistova et al. 2003). The widespread use of these chemicals in the 1950s and their subsequent release into the environment led to a significant decline in eagle populations worldwide. These declines led to many long-term population monitoring programs beginning in the 1960s, many of which are still in use today (Gerrard et al. 1992; Potapov et al. 2000; Bowerman et al. 2002; Haworth et al.

2006; Helander et al. 2008; Nye 2008). In Minnesota, the bald eagle population at Voyageurs National Park (VNP) has been continuously monitored since 1973 (Grim & Kallemeyn 1995).

Along with toxic substances, severe weather and lack of food may be keeping bald eagles from reaching full reproductive potential (Cole 1979). Nesting chronology has recently been shown to be an effective measure of environmental alterations due to global climate change (Grand 1992; Crick & Sparks 1999). Because long term data sets are available for many species and at many locations around the world, avian population data can be used to test hypotheses pertaining to abiotic stressors and climate change model sensitivity. Many avian populations are nesting earlier and these changes have been directly related to changes in weather patterns and/or changes in ecological constraints on nesting and carrying capacity (Brown et al. 1999; Dunn & Winkler 1999; Rubolini et al. 2007; Møller 2008).

Here we report the results of a study on nesting chronology of bald eagles within VNP, Minnesota, 1989-2009. The primary objective of this study was to evaluate how nesting chronology may indicate global climate change. Secondary objectives were to determine if the four major lakes—Rainy, Kabetogama, Namakan, and Sandpoint, differ in response to climate change; determine the relationship between lay date and minimum, mean, and maximum temperatures in January, February, March, and April; determine the relationship between lay date and ice-out date; and to determine whether or not relationships exist within nests with more than 5 years of monitoring data between 1989 and 2009.

Methods

Study Region

VNP is located along the border of the United States and Ontario, Canada. VNP lies between latitude 48° 20′ and 48° 40′ N and longitude 92° 25′ and 93° 15′ W. The park encompasses 88,628 ha with 30 named lakes; 96% of the park's total lake area is comprised of four major lakes: Rainy, Kabetogama, Namakan, and Sandpoint (Figure 3.1). Kabetogama Lake is entirely in Minnesota, but parts of Rainy, Namakan, and Sandpoint are in Ontario. Bald eagles build nests on islands throughout these lakes and along the primary shorelines of the lakes (Grim & Kallemeyn 1995). Land elevations in the park range from 337 to 430 m above sea level (Grim & Kallemeyn 1995).

Voyageurs has a continental climate with moderately warm summers with a mean July temperature of 19°C and long, cold winters with a mean January temperature of -17°C (Kallemeyn et al. 2003). The park experiences freezing weather into June and is subjected to polar air throughout most of the year (NOAA 1993). Heavy snows may persist into May (Grim & Kallemeyn 1995). Precipitation ranges from 16.3 mm in February to 101 mm in June (www.weather.com). Average annual precipitation is 62 cm (Kallemeyn et al. 2003).

"Ice-out" describes the time when the ice on lakes melts. Bald eagle nesting is centered around this time, as fish spawns create a readily available food source. Data on ice-out dates is only kept for Kabetogama and Rainy Lakes. Ice-out on Kabetogama usually occurs 4 to 5 days before ice-out on Rainy Lake. Productivity and reproductive

success have been shown to be significantly lower in breeding seasons with later ice-out than usual (Grim & Kallemeyn 1995).

Data Collection

The National Park Service has been monitoring the distribution and reproduction of bald eagles at VNP by aerial surveys annually since 1973. An observer on each flight noted the nest tree species, reproductive status (e.g., adult incubation/brooding behavior, eggs, or chicks), and determined location (latitude and longitude) with Global Positioning System (GPS). The first survey is conducted around April 10^{th} to determine nest occupancy, and a follow-up survey is conducted around June 10^{th} to determine productivity and reproductive success. If the nest was successful, the number of young, stage of development, tree condition, and nest access from the ground were recorded. From the observer's notes, field crews were directed to the nests at the appropriate times for sampling. Nestling eagles were sampled at five to nine weeks of age, starting in June each year. Exact nest locations were determined on the ground using GPS.

At the nest, a trained crew member climbed the nest tree. Once the climber was secure at the nest, a nestling eagle was captured, placed in a restraining bag, and lowered to the ground. Nestlings were removed from the restraining bag then placed on their backs with their feet bound with elastic bandages to avoid injury to the bird or handler. Eighth primary feather and footpad lengths were measured with a ruler. With these measurements, we used the methods developed by Bortolotti (1984) to determine sex and then estimate the age of the nestling. After sampling was completed, we banded the nestlings with a size 9 U.S. Fish and Wildlife Service (USFWS) rivet band, put them

back in the restraining bag and then returned them to the nest. Capture, handling, and sampling methods were approved by the Institutional Animal Care and Use Committee (IUCAC) at Clemson University and Michigan State University. All activities were conducted under Federal and State permits.

Data for this study spanned from 1989-2009, except three years: 1990, 1991, and 1994, for a total of 18 years. Over this time, 115 nests were found: Kabetogama had a total of 42, Namakan had 16, Rainy had 49, and Sandpoint had 8. Seventeen nest sites were surveyed 5 or more years. Over the 18 year period, Kabetogama had 93 nest visits over all 18 years; Namakan had 50 nest visits over 17 years; Sandpoint had 23 nest visits over 13 years; Rainy had 105 nest visits over 17 years.

Minimum, mean, and maximum temperature for the months of January, February, March, and April, were obtained from the International Falls Weather Station through the MNgage Minnesota-area Volunteer Climate Observing Program and Weather Underground (2010). Dates of ice-out were obtained from the International Falls Daily Journal, a local newspaper which has kept records of local ice-out data for more than 40 years.

Data Analysis

The analysis of changes in lay day of year (DOY) from 1989 through 2009 proceeded in six stages. All were analyzed with the JMP 8.0.1 statistical analysis package (JMP 2009). Significance was accepted at $P \leq 0.05$ for all tests. Stages one through three were conducted on all VNP data. The first stage involved a simple regression model with lay DOY as the response variable and year as the predictor

variable. No attempt was made to adjust or correct for individual nest or lake differences. The second stage included lake as an effect in the model to adjust for inherent differences in lay DOY across the nest sites in the different lakes, and to ensure these differences were not confounded with random error. The third stage involved including nest site as a random effect in the model to adjust for inherent differences in lay DOY across the breeding areas, and to ensure these differences were not confounded with the year predictor variable.

Stages four through six involved a data set that included only nest sites with records of five years or longer. This allowed us to analyze trends with only the "best" part of the data set so that nest sites with limited records did not have undue influence on the analysis. These stages proceeded exactly as stages one through three did: stage four was a simple linear regression, stage five corrected for lake, and stage six corrected for nest site.

To determine if there were any relationships to earlier lay dates, we analyzed several nest site characteristics as they related to DOY for laying. We evaluated minimum, mean, and maximum temperature for January through April, and ice-out dates for Rainy and Kabetogama Lakes. To determine effects of average monthly temperature for January through April on DOY for laying, we utilized a simple regression model with lay DOY as the response variable and minimum, mean, and maximum temperatures for each month as the predictor variable. Ice-out data was first evaluated in a simple regression model with ice-out date as the response variable and year as the predictor

variable. A second simple regression model was then evaluated with lay DOY as the response variable and ice-out date as the predictor variable.

Results

The six stage analysis was conducted in order to determine unconfounded correlations between lay DOY and year. In the first stage of analysis, simple linear regression showed that the Julian dates of first egg laid decreased over the 1989-2009 period, but the trend was not statistically significant (-0.0466 d/y, P=0.2352). All six stages were similarly not statistically significant, except in stage two, the date of first egg laid for Kabetogama Lake significantly increased (0.331 d/y, P=0.0011).

Analysis of temperature data for January through April showed that minimum, mean, and maximum temperatures were positively and significantly related to lay DOY in January (0.097 d/°F, P=0.0320; 0.107 d/°F, P=0.0335; 0.125 d/°F, P=0.0275) and negatively and significantly related in March (-0.205 d/°F, P=0.0042; -0.311 d/°F, P=0.0018; -0.317 d/°F, P=0.0006). Further analysis of January and March temperatures in VNP, however, revealed that while lay DOY is earlier when temperatures are higher, minimum, mean, and maximum temperatures in this area are actually decreasing over time. February and April temperatures were not statistically significant (Table 3.1).

The relationship of ice-out date to year was negative but not significant (-0.334 d/y, P=0.0997). The relationship of lay DOY to ice-out date was positive but not significant (0.08 d/y, P=0.0640).

Discussion

Related studies show that climate change increases competitive relationships (Ahola et al. 2007), causes population declines (Both et al. 2006), causes range shifts and extinction (Sekercioglu 2008), and alters breeding behavior (Carey 2009; Crick, 2004; Seavy et al. 2008). Earlier nesting chronologies have been demonstrated in a variety of species. In a population of Mexican Jays (*Aphelocoma ultramarina*) in Arizona, warmer minimum temperatures before and during breeding from 1971 to 1998 caused dates of first nest and first clutch to become earlier by 10.8 and 10.1 days, respectively (Brown et al. 1999). One data set spanning 57 years found that laying data was related to temperature or rainfall for 31 of 36 species (Crick and Sparks 1999). A 21 year study of marsh tits (*Parus palustris*) revealed a significant relationship between mean laying date and air temperature (Dolenec 2006). In another study from 1980 to 2002, collared flycatchers (*Ficedula albicollis*) bred an average of 0.4 days/year earlier (Weidinger and Kral 2007). This was correlated with an increase in temperature. Increase in May temperatures combined with reduced human interference at nest sites was correlated with Welsh hen harrier (*Circus cyaneu*) population increases over a 20 year period (Whitfield et al. 2008). Date of egg-laying in tree swallows (*Tachycineta bicolor*) in North America from 1959-1991 advanced up to 9 days (Dunn and Winkler 1999). In a study of black kites in Italy from 1994-2002, nesting was becoming earlier by 0.4 days/year (Sergio 2003). A study of red-winged blackbirds (*Agelaius phoeniceus*) in Ontario over 25 years correlated earlier nesting with the North Atlantic Oscillation Index (NAOI) and breeding season was shown to last longer, but there was no advancement in laying date

(Weatherhead 2005). In one study of six bird species, laying date advanced in all cases except those where temperature was not variable over the 50 year period (Torti and Dunn 2005). In contrast to our study, an entire community of Antarctic seabirds studied over 55 years were shown to arrive 9.1 days later and lay eggs 2.1 days later than 50 years previous (Barbraud et al. 2006). This is more likely linked, however, to a change in sea-ice extent and subsequent declines in food sources for these birds.

In this study, the trend in lay date was not significant for the initial analysis, so nest sites were further subdivided to determine if significance existed at different levels in the data. Kabetogama Lake nest site lay dates were significantly later over time. Analysis of temperature data revealed that January and March temperatures are related to lay date; further analysis, however, revealed that January and March temperatures in VNP are decreasing over time.

One possible reason that we did not find significant relationships may be the power of the study. Power analysis of our dataset revealed that to see significance, we would need over 2000 surveys, as in our Michigan study. Another reason we did not find significant relationships may have been that all VNP lakes are inland, like those inland sites in the Michigan study. In the Michigan study, inland areas did not show as significant of a relationship because ice-out is much later than in other areas. Although our data showed few significant relationships between egg laying and climate change, climate change cannot be ignored as a factor influencing these eagles. Bald eagles in VNP are commonly exposed to severe weather during egg laying and incubation and

until nestlings gain thermal regulatory independence in late March to mid-June (Grim & Kallemeyn 1995).

Analyses on a number of other climate change variables have been conducted. Due to the nature of our long-term monitoring project, there were limitations to our reporting. The primary objective of our monitoring project was to evaluate trends of bio-accumulative chemicals of concern in the VNP ecosystem; therefore, all temperature data was gathered *post hoc* via the International Falls weather station (HIDEN Minnesota Climate Networks, Weather Underground). Additional *post hoc* analyses could be conducted to determine the possible influence of precipitation (Brown et al. 1999); ice cover and the resulting effects on food availability (Møller 2008); and North Atlantic Oscillation (NAO; Rubolini et al. 2007). Because of the extensive time span of our monitoring project, we will be able to conduct additional analyses as well as initiate new methods of collecting data in order to monitor the effects of climate change within VNP.

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Table 3.1 Regression results of lay day of year (DOY) in relation to minimum, mean, and maximum temperatures of January through April, 1989-2009, VNP, MN.

	January		February		March		April	
	Slope	P-Value	Slope	P-Value	Slope	P-Value	Slope	P-Value
Min	0.097	0.0320	-0.072	0.0655	-0.205	0.0042	0.018	0.4445
Mean	0.107	0.0335	-0.083	0.0825	-0.311	0.0018	-0.023	0.4165
Max	0.125	0.0275	-0.098	0.0680	-0.317	0.0006	-0.029	0.3685

Figure 3.1 Voyageurs National Park, MN, with Rainy, Kabetogama, Namakan, and Sandpoint denoted.

CHAPTER FOUR

CONCLUSIONS

The objectives of this study were to determine Julian lay dates of first eggs laid in bald eagle nests in MI and MN; to determine if lay date changed over the study period by using a regression model with lay date as the response variable and year as the predictor variable; to determine if change in lay date correlated to changes in habitat, including: temperature, elevation, ice-out, latitude and longitude, distance from major water sources, and habitat location; and to determine if trends in lay date were more significant in areas with more years of surveys over the study period.

Julian lay dates were determined *post hoc* using nestling sex and eighth primary feather lengths recorded during surveys of bald eagles in MI from 1988-2008 and in VNP from 1989-2009.

This study confirms that lay date changed over the study period in both MI and MN. In MI, we found both significant and inverse trends in Julian date that averaged -0.2 d/y over the study period. In MN, we found an inverse but not significant trend in Julian date that averaged -0.047 d/y over the study period.

Results of this study indicate that many habitat aspects can be further evaluated to determine their influence on lay date. In MI, mean Julian dates of first egg laid were earlier for breeding areas from GL, AN, and IN categories between 1988 and 2006. All were significant except IN, which was therefore further evaluated to determine if certain breeding area characteristics would show significance in relation to Julian date. Location, habitat type, elevation, latitude and longitude, and distance to the Great Lakes

were all not significant, but when breeding area was included as a random effect to adjust for all inherent differences, a significant trend was found for IN. In MN, mean Julian dates of first egg laid were earlier but not significant. Further analysis revealed that nests in Kabetogama Lake showed a significant increase in lay date over time; all other lakes decreased, but were not significant. Minimum, mean, and maximum temperatures in January, February, March, and April revealed that only March temperature was a significant factor in determining lay date. Ice-out data showed a negative trend that was not significant.

Lastly, this study revealed that it may be beneficial to reduce the dataset to only areas with many years of surveys in order to see the significance. In MI, 35 breeding areas had more than 10 years of surveys over the study period. Of the 35 breeding areas, 23 showed a negative trend, and six of these were significant. Temperature data in relation to the lay dates of these "best 35" breeding areas revealed that January, February, March, and April mean temperatures are significantly related to this decrease in lay date. In MN, 17 breeding areas had more than 5 years of surveys over the study period. The overall trend for these areas was negative but not significant. After correcting for breeding area, there was no significance.

Due to the nature of our long-term monitoring project, there were limitations to our study. The primary objective of our original project was to evaluate trends of bio-accumulative chemicals of concern, and all temperature data was gathered *post hoc*. Because of the robustness of our monitoring project, we will be able to conduct

additional analyses as well as initiate new methods of collecting data in order to monitor the effects of climate change in the Great Lakes and VNP.